Producing Durable Continuously Reinforced Concrete Pavement using Glass-ceramic Coated Reinforcing Steel

Principal Investigator:	**Sean W. Morefield**	**CERL**
Co-Investigators:	**Brett A. Williams**	**GSL**
	Charles A. Weiss, Jr.	**GSL**
	Philip G. Malone	**GSL**
	Mike Koenigstein	**PPEC**

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE **FEB 2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **Producing Durable Continuously Reinforced Concrete Pavement using Glass-ceramic Coated Reinforcing Steel**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Corps of Engineers,CERL,PO Box 9005,Champaign,IL,61822**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
2010 U.S. Army Corrosion Summit, Huntsville, AL, 9-11 Feb.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**23**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Presentation

- The Corrosion Problem in Pavements
- Nature of the Vitreous-Ceramic Coating
- Ease of Application to Reinforcement Steel
- Bond Strength and Corrosion-Resistance
- Field Demonstration Program
- Testing in Reinforced Concrete Pavement
- Summary of Current Status

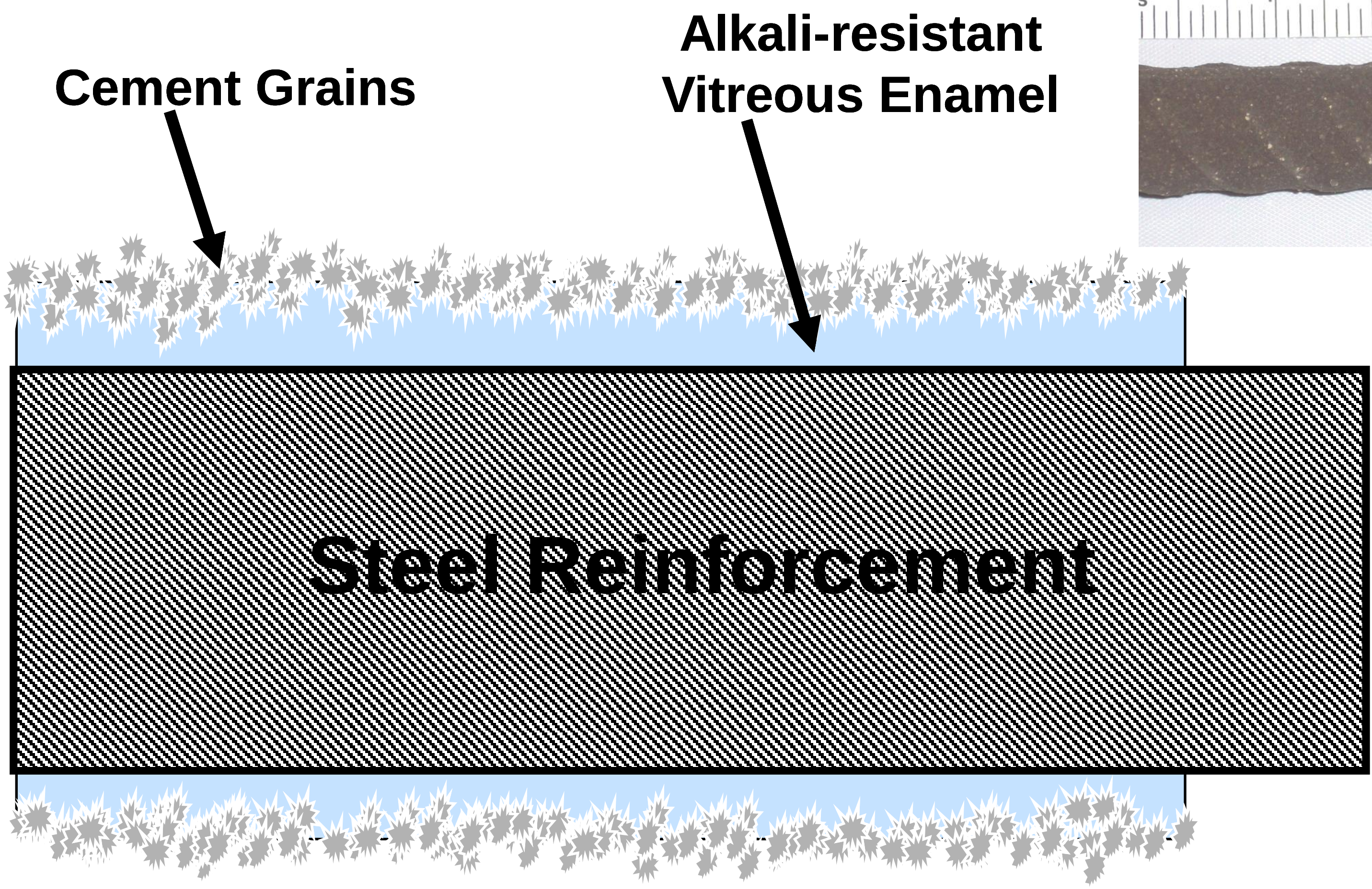
Corroding Steel Reinforcement is a Major Problem in Continuously Reinforced Concrete Pavement

The 600% volume change in the iron to iron oxide formation put the concrete in tension and it cracks an spalls

Framing the Problem

- The predicted service life of continuously reinforced concrete pavement can be shortened if the rebar in the pavement corrodes prematurely and delaminates the pavement
- Moisture and chlorides can move through the natural porosity of concrete and the cracks in the pavement
- Application of chlorides from natural sources and from deicing compounds can greatly speed up the corrosion process
- The concrete in the transition zone at the surface of the reinforcement steel is often the most permeable part of the concrete

Schematic of Ceramic-Vitreous Enamel Coating



Enamel protects and steel from corrosion; the cement grains hydrate and bond to surrounding concrete

Properties of Coating

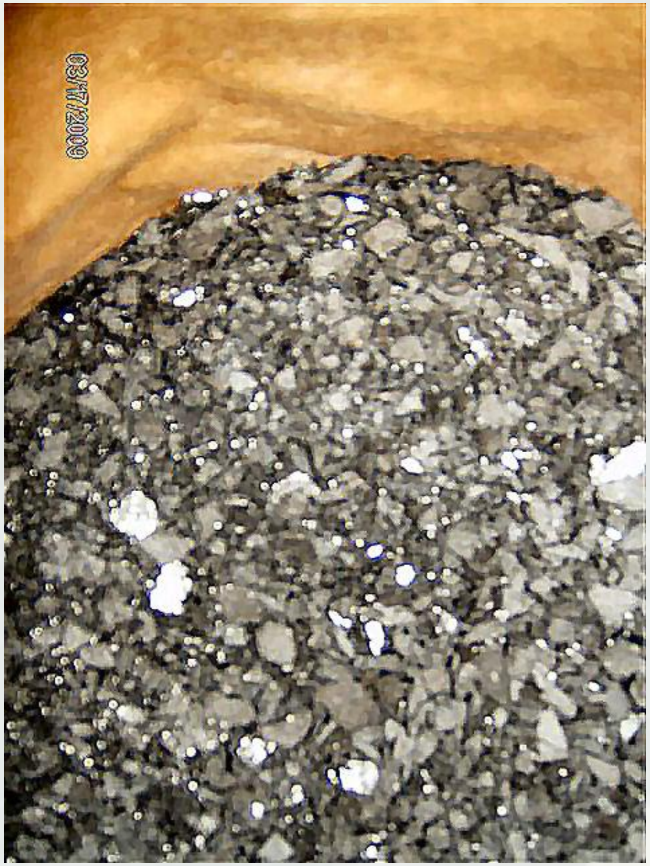
- Covers the reinforcement with an insulator
- Does not delaminate from the steel
- Does not allow the permeable layer at the interfacial zone to form
- Maintains the alkalinity at the surface of the steel reinforcement if the enamel is broken
- Embedded cement grains hydrate if enamel is cracked to self-heal with the formation of calcium silicate hydrate

Goal is to prevent spalling!

Vitreous-Ceramic Coatings

- Formed by fusing glass to steel at temperatures between 750 C and 850 C forming a true interlayer of iron-rich glass on the surface of steel.
- Considered to be the most durable coating that can be put on steel.
- Vitreous enameling is used primarily to prevent corrosion of underlying steel.
- Addition of ceramic to the glass provides a reactive component that can form a bond to hydrating Portland cement in fresh concrete.
- New bonding enamel can both strengthen the bond of the steel surface to surrounding concrete and prevent corrosion of the steel reinforcement.

Vitreous Enamel is Glass Fused to a Metal Substrate



Cobalt and nickel-rich glasses will fuse tightly to steel forming an iron-rich interface.

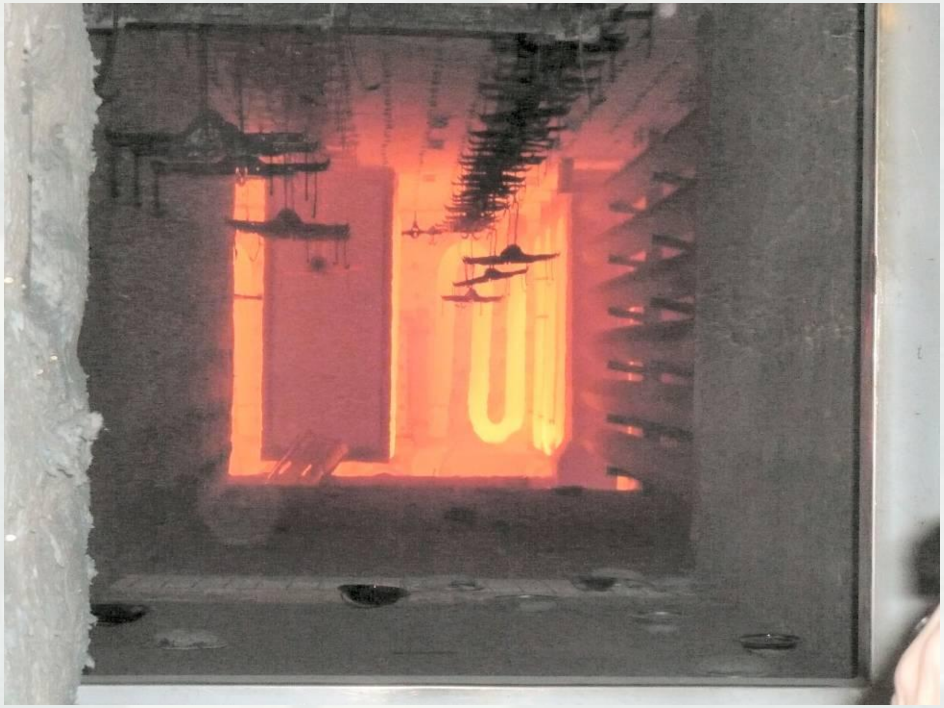
Composition of the glass can be altered to change chemical resistance, bonding properties, coefficient of expansion

Specialized Frits Used to Developed Needed Properties

Steel-to-concrete bonding frit contains zirconium to make it alkali-resistant and a reactive Ca-silicate ceramic to make it bond.

The slip must flow, stick and the final glass must have proper thermal expansion properties to form a durable, strong, continuous coating.

Firing of a Vitreous Enamel is a Versatile Process



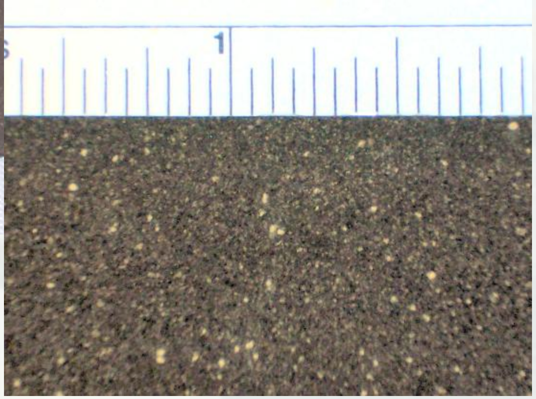
Firing is typically done in minutes at the 750 C to 850° C range.

Fusing the glass can also be done by torch, plasma or induction heating.

Multiple coating and multiple firing can be used to build coating thicknesses as needed. Commercial enameling is a continuous process.

Vitreous-Ceramic Coating On Rebar

Mild steels used in reinforcement enamel well



Portland cement is manufactured by firing the clinker at 1400 C

Enamel application produces no changes

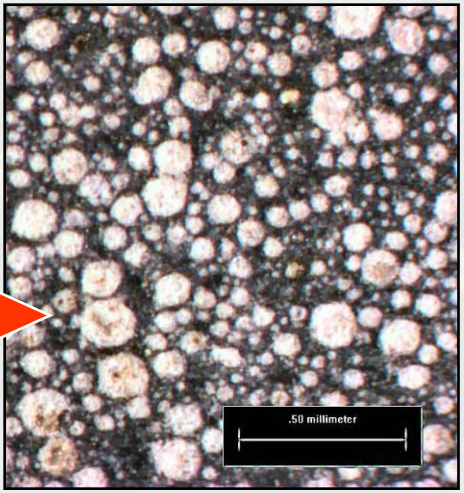
After firing cement grains are embedded in glass enamel

Improved Bond Strength

Treatment	Average Peak Force lbf (N)	Std. Deviation lbf (N)	Average Streng psi (M
Steel fiber embedded in mortar (various published sources)	---	---	295.4 - 3 (2.0 - 2
Steel rods, uncoated embedded in mortar	588.7 (2,618.2)	104.8 (466.2)	298. (2.1
Enameled rods without portland cement embedded in mortar	786.4 (3,497.9)	121.6 (540.8)	391. (2.7
Steel rods, uncoated, surface roughened by grit blasting (reported by PPEC)	--	--	595 (4
Enameled rods with portland cement (acid surface preparation reported by PPEC)	--	--	797 (5
Rods with enamel containing portland	2,500.9	52.9	1,274

~4X change

Hydration of Embedded Cement



Photomicrograph showing embedded cement grains

Moistened surface of rod with bonding enamel show the pH change indicating embedded cement is hydrating

Enameling Provides Excellent Corrosion Resistance

Results of 40-day exposure of mild steel test rods with and without enamel in 3.5% NaCl solution at 20 °C

Coated rods would only corrode if the enamel was intentionally removed.

Quartz sand saturated with 3.5% NaCl solution was test bed

Field Test at Corpus Christi Army Depot

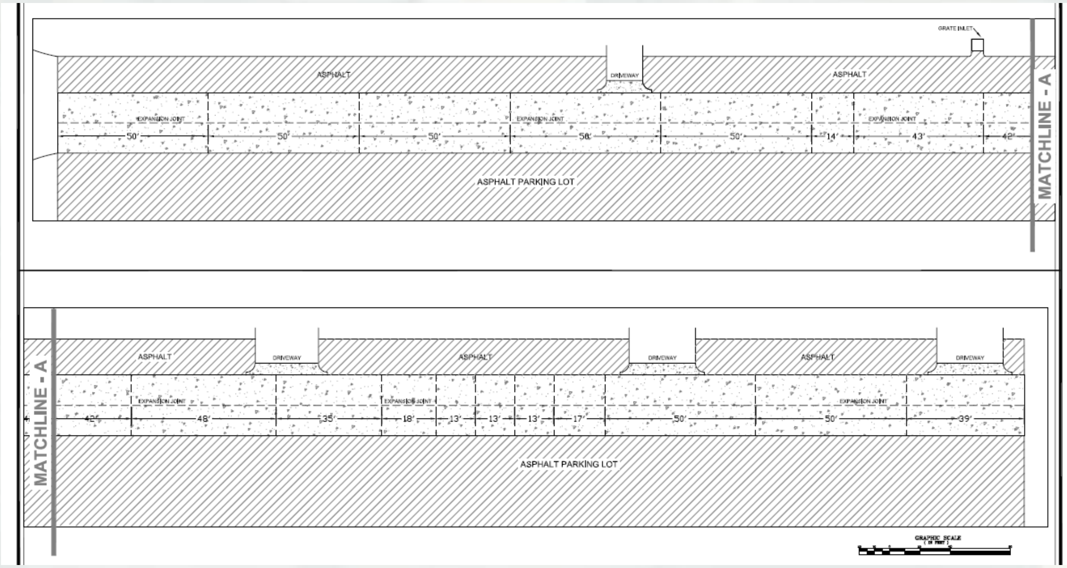
Proximity to Gulf of Mexico makes location prime test site

Corrosion of stirrup rebar in support beam caused end of the beam to fall off

Project replace beams 14,400 sq. ft. of CRCP

CCAD Continuously Reinforced Concrete Pavement Section

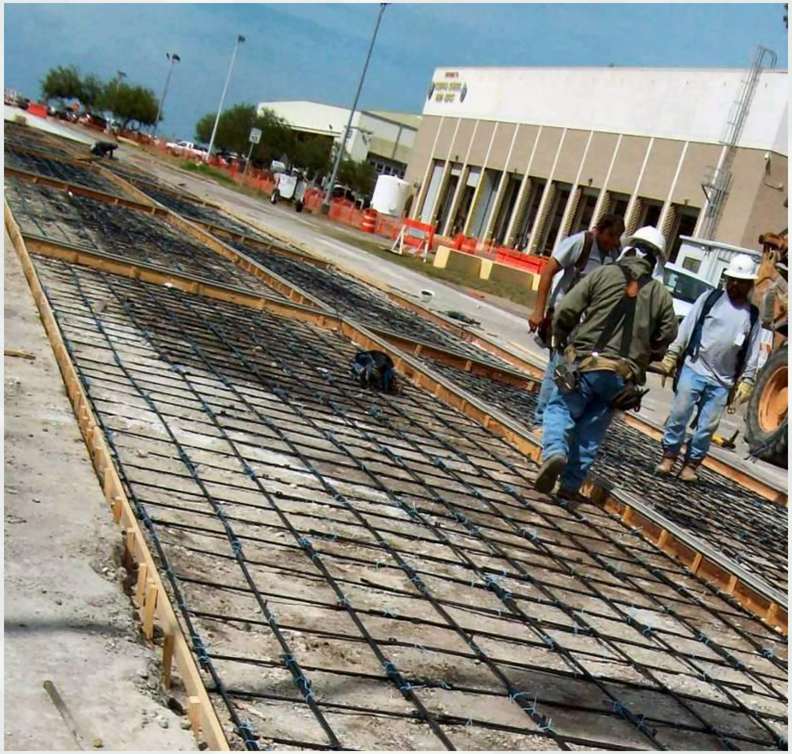
- 14,400 sq ft
- 600 linear ft of concrete
- 300 linear ft of curb and gutter
- Pavement 6-in thick
- Design to follow AASHTO GHDS-5-M (5000 VPD)
- Post-fabrication enameled #3 and #4 rebar throughout



- Corrosion rate will be measured using Linear Polarization Resistance (LPR)
- Crack width surveys will be conducted
- Test samples modeled after G109 test specimen will be monitored

Crecy Street Test Site at CCAD (1)

- Section is 300 linear ft. 24 ft. wide
- Total area = 14, 400 sq. ft.
- Construction used #3 (3/8 in.) rebar as lateral bars
- Longitudinal bars were #4 (1/2 in.) rebar
- Lateral bars spaced at 12.5 in. centers
- Transverse bars spaced on 15 in. centers



Crecy Street Test Site at CCAD (2)

- Pavement is 6-in. thick
- Bars are positioned at mid-depth
- Bars were overlapped to form splices
- The overlaps vary from 12 in. to 20 in.

Finished Section of CRCP at Crecy Street Test Site

The pavement design follows AASHTO GHDS-5-M for a 5000-car per day traffic load

Photo from August 18, 1909

Initial Test Results

- **No corrosion has been detected from either bare or coated bar at test site**
- **Results from the G109 tests suggest the coated bar is significantly less susceptible to corrosion than the bare bar**
- **No crack measurements have been made to date**
- **Corrosion measurement will continue for**

~ 2 years

Summary

- Enameled rebar with a reactive ceramic component can potentially be used to increase the concrete-to-steel bond strength
- The enameled rebar can be manufactured using the conventional enamel application methods and modification of standard alkali-resistant porcelain enamel
- Laboratory tests suggest the reactive vitreous enamel can produce significant improvements in the performance and service life of reinforced concrete
- Field demonstrations have started in 2009 to evaluate the usefulness and economic benefits of a bonding enamel coating in continuously reinforced concrete pavement

ACKNOWLEDGEMENTS

The funding for this study was provided by Office of the Under Secretary of Defense (Mr. Dan Dunmire and Dr. Lewis Sloter) and ACSIM-IMA (Mr. David Purcell and Mr. Paul Volkman).

QUESTIONS?